船尾管油の分析

技術研究所　橋本高明、佐々木千一

１．まえがき

船尾軸・軸受の予防保全管理が可能となり、適合船には船級符号に PSCM(Propeller Shaft Condition Monitoring) を付記し、使用潤滑油の分析・判断を船主殿の自主管理において行われる事となった。このルールは 1997 年７月に導入され、現在、約 90 隻が当管理方式を採用している。

ルール導入に先立ち、ホワイトメタル軸受に使用中の船尾管油の分析につき研究報告を行った時点では、軸受の損傷例も少なかったが、その後の研究継続で新たな損傷例も出て来たので、参考のためにそれらを報告し、加えて、プラスチック軸受に使用中の潤滑油の分析につき中間報告をする。

２．ホワイトメタル軸受での損傷例

検査においてホワイトメタル軸受の損傷が確認され、故にその時使用されていた潤滑油の分析がなされた例の、使用油分析結果を表１に示した。

表１　軸受がリメタルされたケースの潤滑油分析結果例

船舶名 分析項目（カッコ内管理基準値）	Ship A	Ship B	Ship C	Ship D	Ship E	Ship F
金属元素、　ppm						
Ｆｅ　(50)	237	10	55	45	12	8
Ｓｎ／Ｐｂ　(20/20)	90 / 10	150 / 2	279 / 15	117 / 5	31 / 321	64 / 2
Ｃｕ　(50)	15	56	162	7	4	6
Ｎａ　(80)	69	44	290	646	288	25
フェログラフィ、DR 値 W.P.C/ml　(30)	52	60	167	431	76	68
赤外酸化度、　(10) Abs. unit/cm	2	7	8	16	23	5
分離水、　%v　(1)	痕跡	痕跡	痕跡	痕跡	約 8	認めず
参考：油中含水量、%v	0.43	0.28	0.74	1.88	1.36	0.5 以下

特に、Ship F については、継続的な分析結果が有り、軸受メタル損傷前の分析値の勾配に大きな意味が有りそうなので、分析値をグラフ化し参考に供したい。（図１参照）

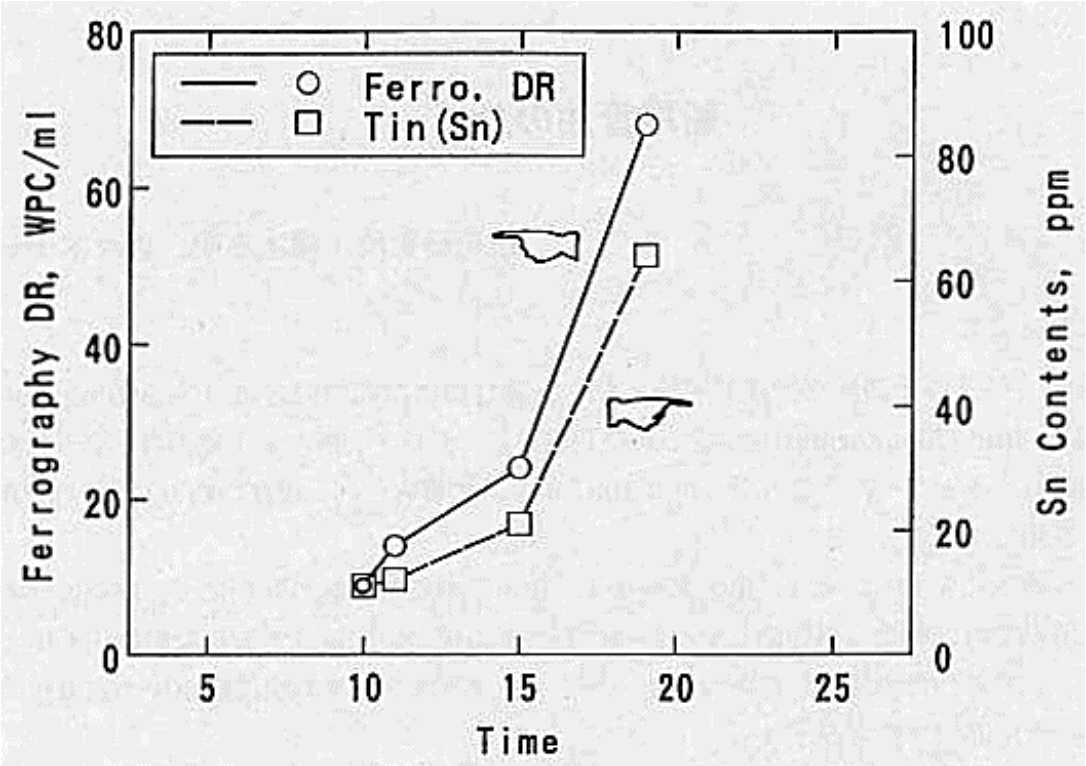


図１　Ship F の使用油分析値の経過

Ship F は就航後数年経ってより、船尾管油の当会の分析項目による分析を開始した。図１における、時経数 10 ポイント時 がその初回で有る。20 ポイント時 直前のデータが船尾管検査で異常が発見された時の、使用油の分析値である。

３．考察

3.1　使用潤滑油分析値の管理基準値案は、約 150 隻の船尾軸・軸受検査結果とその時使用されていた潤滑油の分析結果より判断して設定された。案作成時の軸受でリメタルされたケースは１件のみであった。現在、６件の事例の潤滑油分析結果を有している。この６件のデータから判断して、1997 年に設定した管理基準値はいましばらくは適応出来ると判断される。将来、更にバックデータの蓄積がなされれば、更に精度の高い管理基準値に整備しうると思われる。

3.2　図１のグラフにおいて、10-15 ポイント時の経時変化についてもっと多くのデータの蓄積が必要である。この勾配が意味を有している可能性もあるので、データが増えた時点でこの勾配を数値化したく考えている。

４．プラスチック軸受

最近は大型船にもプラスチック軸受が採用されるケースも出てきて、新たに使用潤滑油の追跡調査を行っている。

Ship G はプラスチック軸受採用船であるが、1998 年 10 月に使用潤滑油を新替えして後、当方でも潤滑油の分析を続けている船舶である。

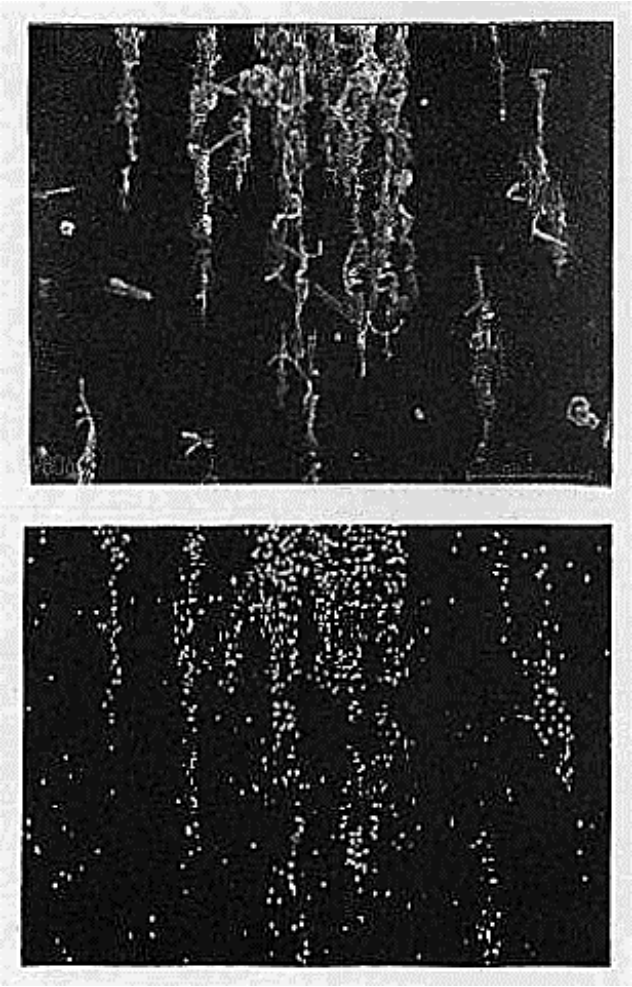
表２はその分析結果である。

表２　Ship G の使用油分析結果

採取月 分析項目	1998 10 月	1999 1 月	1 月(再)	6 月	2000 1 月	6 月	8 月	
金属元素、ppm Fe Sn / Pb Cu Na	 2 0 / 0 1 4	 2 0 / 0 1 8	 2 0 / 0 1 8	 5 0 / 1 2 2	 4 0 / 1 1 8	 8 0 / 0 2 2	 9 0 / 1 2 6	
フェログラフィ、 DR 値、WPC/ml	42	94	121	166	303	118	103	
赤外酸化度、 Abs. unit/cm	7	12	9	4	4	5	*	*後日 報告
分離水、　%v	認めず	認めず	痕跡	認めず	認めず ／混濁	認めず ／混濁	認めず ／乳化	
参考：油中含水 量　%v	0.80	0.83	1.91	3.40	0.88	1.40	1.37	
灰分、　%m	0.60	0.60	0.61	0.50	0.58	0.56	0.55	
メンブレンフィルタ 夾雑物、mg	10.0	24.0	24.0	80.4	80.4	128**	163**	
				**脱水後 水分= %		**脱水後 水分= 0.78%	**脱水後 水分＝ 1.09%	

プラスチック軸受の潤滑油の分析法に関しては、未だ考察しうる域に達していないが、少なくとも、ホワイトメタル軸受使用油の分析項目では判断し得ない事を感じ取ったので、急遽、灰分とメンブレンフィルタ夾雑物の分析を追加しその有効性を試みている。表２において、金属元素(ppm)と灰分(%m)が増加していないので、軸に異常は発生していないと言える。又、赤外酸化度(Abs.unit/cm)も低いレベルを保っており、基油の劣化は無いと判断しうる。フェログラフィ DR(WPC/ml)とメンブレンフィルタ夾雑物(mg)が上昇勾配にあり、軸受材の摩耗粒子が油中に増加していると判断して良かろう。

フェログラム上に捕捉された摩耗粒子の X 線二次電子イメージ（図２参照）では、かなりの量の摩耗粒子がマグネットの N-S 極の方向に平行に並んでいる。中には、切削形摩耗粒子も見受けられる。しかしながら、EPMA による同一箇所の Fe-X 線イメージ（図３参照）では Fe 粒子 は連続でつながっておらずそれぞれの粒子が単独で補足されているだけである。かつ、切削形の Fe 摩耗粒子は存在していない。従って、図２で見られた摩耗粒子の多くは樹脂材の摩耗粒子であろうと推察できる。さらに EPMA の感度を上げて切削形摩耗粒子を観察したものが図４及び図５である。摩耗粒子の中に非常に微細な（約 0.1 ミクロン以下）Fe 粒子が均一に散らばって埋め込まれている事が判る。フェログラフィで Fe 粒子以外の摩耗粒子を補足しているのはこのためであろうと判断できる。



フェログラム上の摩耗粒子

図２　X 線二次電子イメージ

図３　図２の Fe-X 線イメージ

図４　切削形摩耗粒子の X 線二次電子イメージ

図５　図４の Fe-X 線イメージ

５．あとがき

ホワイトメタル軸受の潤滑油分析に関しては、現在設定している管理基準値の枠は概ね適正と判断しうる。将来、更にデータが集積されればより精度の高い管理基準値を得るよう考察を行いたく考えている。

プラスチック軸受の潤滑油分析については、現在試用中の分析法による状態判断と、船尾軸・軸受検査結果との相関性を検討する必要があるため、今しばらくの猶予を頂きたい。

共に、より良い管理基準値を設定するためには、船主殿をはじめ造船所殿等関係者のおおいなるご協力が必要であり、謹んで今後の更なるご協力を御願い致したい。

（尚、部分的により詳しく述べたものに 1999 年ポーランドにて開催されたシンポジウム、Marine Technology III での研究発表が有るので参考資料として、巻末に添付した。参照いただければ幸いである。　Title: Condition monitoring of stern tube lubrication　）

「船尾管油の分析」参考資料

Marine Technology III

Organised by:
The Technical University of Szczecin, Poland
And Wessex Institute of Technology, UK

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Condition monitoring of stern tube lubrication

T. Hashimoto,(1) N. Baba,(1) H. Aoki(2)
(1)Research Institute, Nippon Kaiji Kyokai(ClassNK) Research Center
1-8-3, Ohnodai, Midori-ku, Chiba 267-0056, Japan
EMail: t.hashimoto@classnk.or.jp
(2)Classification Department, Nippon Kaiji Kyokai(ClassNK)
4-7, Kioi-cho, Chiyoda-ku, Tokyo 102-8567, Japan

Abstract

The propeller shaft and white-metal bearings of a shaft are normally inspected every five years by the surveyor of a ship classification society. But this work is time-consuming to ship owners and dangerous at practice site due to its heavy load. We have studied for years whether the analysis of lube oil in service can be used as an alternative to the aforementioned time-based survey.
We found that when the wear metal particles derived from propeller shaft and bearing metal in oil is below 30 W.P.C./ml by Ferrograph Analysis(Ferrography) Direct Reading(DR) method, it can be clearly said that the stern tube is in a satisfied lubricating condition and it is not necessary to withdraw the propeller shaft for inspection. We also report some severely damaged cases which Ferrography DR showed to be over 50 W.P.C./ml.
Our new experiences, in addition, of wear particles in oil which is in service with plastic stern tube bearings is briefly reported as an interim report. Based

on our experiences obtained from this study, we have set up the condemning limits of used oil and started the Preventive Maintenance System for Oil Lubricated Propeller Shaft(Condition-monitoring-based Survey).

1 Introduction

The stern tube shaft and bearing metal of ships are usually surveyed every five years by a surveyor of a ship classification society. But, even a five year inspection interval, it requires a lot of manpower, time, and cost. And, it is reported in some cases that there is a possibility of damaging the bearing metal running surface by reinstalling that heavy propeller shaft.
Therefore, the authors' company developed a research project, for ships with oil lubricated stern tubes, whether the used oil analysis can be used as an alternative to the survey of propeller shaft and bearing metal of the stern tube(S/T) of ships. After the research results from over 120 random surveys and the approximately 20 vessels' consecutive years planned surveys, we have reached the conclusion that the condition-monitoring-based survey is applicable instead of the time-based survey on some conditions.

2 Oil Analysis

The S/T oil in service was sampled for the following oil analyses. Four test items were thought to be enough for the evaluation of lubricating condition.

1. Very fine metal wear particle contents(less than several micron in size) by Inductively Coupled Plasma(ICP) Emission Spectrometer or SOAP Analyzer, ppm
2. Relatively large metal wear particle contents(more than several micron to approx. 150 micron in size) by Ferrography Direct Reading, W.P.C./ml
3. Base oil deterioration by Fourier Transform Infrared Spectrophotometer (FT-IR), IR Oxidation, Abs. unit/cm
4. Water content by FT-IR, % v

3 Random Sampling

As a first step, random 125 S/T used oil samples were landed for analysis from the vessels which propeller-shaft and bearing metal were surveyed at the Special Survey(five year point after the previous survey). All survey results were classified into the four categories described in Table 1. The percentage of each category is illustrated in Figure 1.

Table 1: Categories of Random Survey Results

Category	Remarks
Condition A	No damage, quite satisfied.
Condition B	Very light damage, which allows refitting without any repair work.
Condition C	Light damage, which required light repair works. (e.g. scraping with oil stone and/or scraper).
Condition D	Severe damage, which required renewal of bearing metal.

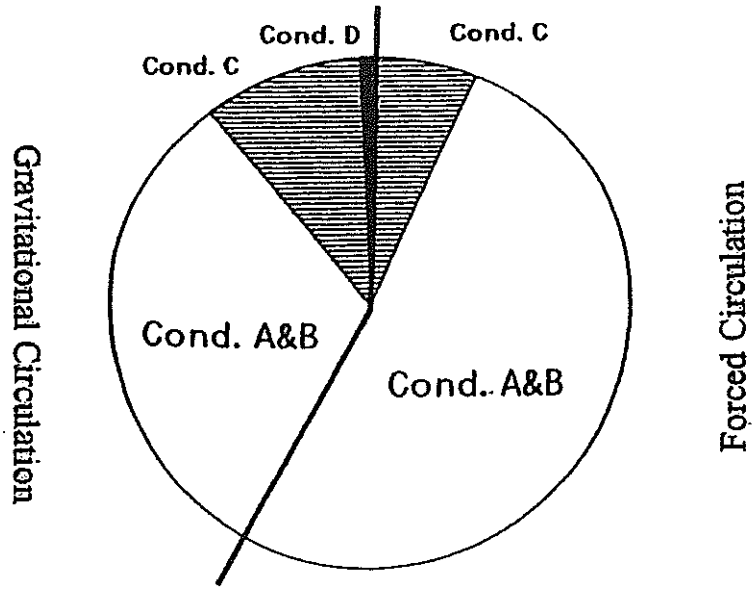

Figure 1: Random Survey Results[1]

Condition A and Condition B is combined in the same field as a satisfied condition in the figure.
Regarding the oil circulation, there are two kings, one is Forced Circulation and the other is Gravitational Circulation.
In this report, we do not consider the differences between two circulation systems, but, Condition A and B was 83 percent in total. Condition C was 16 percent in total. And Condition D was just one case at that time and 0.8 percent.

On the other hand, the analysis results of oil samples were relatively in a broad range, the reason supposed was that a sampling point was not fixed(depended on the ships' hands judgements). But as the averages, they were summarized as shown in Table 2.

Table 2: Averages of Oil Analysis Results

Test Items	Condition A and B	Condition C	Condition D
Metal Elements, ppm			
Fe / Ni /Cr	9 / 1 / 1	13 / 1 / 1	237 / 3 / 5
Sn / Pb	3 / 7	5 / 7	90 / 7
Cu / Na	12 / 71	12 /67	15 / 69
Ferrography, W.P.C./ml*	33	65	52
IR Oxidation @5.85 um, Abs. unit/cm	4	4	2
IR Water, % v	0.9	3.1	0.4

* Wear Particle Concentration /ml

When we compare two categories, i.e. Condition A /B and Condition D, the most significant differences are the wear metal particles' contents in oil, i.e. Ferrous(Fe) and Tin(Sn) contents and ferrography Wear Particle Concentration.
Other items like base oil deterioration and water content had no difference, respectively. It can be said that the oil oxidation levels of both categories are well within the satisfactory order(below 10 Abs. unit/cm). And the water content are also in the range of acceptable level(less than 1.0 % v). Therefore, it is clear that the damaged case is not caused by the oil deterioration and /or

water contamination itself. In addition, judging from the condition that the large amount of very fine metal particles(Fe and Sn) in oil and relatively some large amount of ferrous particles arrested by ferrography, the authors understand that damaged case might had been proceeding for long hours but not a short time.

4 Tentative Condemning Limits of Used Oil

The authors set up, based on the experiences mentioned above, a tentative condemning limits for controlling lubricating oil in service for the further experimental study; which the oil sampling point is fixed and the sample oil is regularly landed for analysis from 20 vessels for consecutive two or three years. The condemning limits are shown in Table 3.

5 Experimental Study on board Ships

Under the ship owners great cooperation, the authors had run the experimental study for three years aboard 20 selected vessels which installed oil level alarming unit and independent two sensors of bearing metal temperature and had planned to withdraw propeller shaft for S/T survey in the near future.
As the results, we could confirm the lubricating conditions of 11 propeller shafts and the counterpart bearing metals.
Ten sets were Condition A or B. And one set was Condition C, which the running surface of bearing metal was slightly scraped off for flattening.

The oil analysis results of the experimental ships are summarized in Table 4.
The deviations are less on these averages, which means the higher reliability of numerical value itself, in comparison with the data of random samplings.
Though the whole data of oil analysis results were within the aforementioned condemning limits(Table 3), the bearing metal condition of one ship was judged to be refitted after repairing work by a surveyor this time. The photo[2] of Condition C observed this time is shown in Figure 2.

Table 3: Tentative Oil Condemning Limits

Test Items	Upper Limits	Test Methods
Fe	50 ppm	SOAP
Sn	20 ppm	SOAP
Pb	20 ppm	SOAP
Cu	50 ppm	SOAP
Ni	10 ppm	SOAP
Cr	10 ppm	SOAP
Na	80 ppm	SOAP
Ferrography	30 W.P.C./ml	Ferro. D.R.
IR Oxidation	10 Abs. unit/cm	FT-IR
Free Water	1 % v	Visual Inspection after 24 hr settling

Table 3-B: Condemning Limits for Preventive Maintenance System

Items subject to control	Upper Limits	(Alarming Point)
Bearing temperature	45 ℃	(55 ℃)
Wear down(Clearance)	0.2 mm	(0.4 mm)
Lube oil consumption	2 l/day	(4 l/day)

Therefore, the dependability of the oil condemning limits can be said to be roughly 91 percent at this moment.

Table 4: Oil Analysis Results of Experimental Ships

Typical Test Items	Averages
Fe	5 ppm
Sn or Pb	1 ppm
Na	36 ppm
Ferrography D.R.	12 W.P.C./ml
IR Oxidation @ 5.8 um	4 Abs. unit/cm
Free Water	Trace

6 Examples of Damaged Cases

During the random sampling study, the authors faced only one damaged case(Condition D), but while the planned sampling study was going on, we met several damaged cases in the outside of the experimental study ships.
Since the oil analysis results of damaged cases have some meaning for R and D in this field, all data the authors hold are summerised in Table 5 and the typical condition of damaged case is shown in Figure 3..

7 Preventive Maintenance System for Stern Tube

Based on the experiences obtained from two studies described above, the authors' company judged that, the condition-monitoring-based survy by oil analysis can be applied for the oil lubricated vessels on some conditions as the preventive maintenance system(PMS) for S/T. For putting into practice of PMS, the condemning limits of Table 3 and Table 3-B should be accepted and the oil analysis at the continuous and appropreate interval sampling should be run by ship owners.

As of May 1999, 19 ship owners have started the PMS for S/T on their fleets.

Table 5: Oil Analysis Results of Damaged Cases

Test Items	Ship A	Ship B	Ship C	Ship D	Ship E
Metal Elements, ppm					
Fe /Ni /Cr	237/3/5	10/1/0	55/2/5	45/2/1	12/1/0
Sn /Pb	90/10	150/2	279/15	117/5	31/321
Cu /Na	15/69	56/44	162/290	7/646	4/288
Ferrography, W.P.C./ml	52	60	167	431	76
IR Oxidation @5.85 um Abs. unit/cm	2	7	8	16	23
IR Water, % v	0.43	0.28	0.74	1.88	1.35
Free Water, % v	Trace	Trace	Trace	Trace	Apx. 8

8 Next Study on Plastic Bearing for Propeller Shaft

After the above experimental study, the authors have faced new questions on the plastic bearing of S/T, which are recognised as the difficulty of judging the lubricating condiiton by routine analysis explained in **2 Oil Analysis**.

Since the ferrography D.R.,W.P.C./ml, showed to be very high, the microscopic observation followed by X-ray observation was done on particles arrested on a ferrogram.
Many wear particles including cutting wear debris are shown in line with the direction of magnet field(N-S). Refer to Figure 4(Secondary electron image by X-ray). Usually the cutting metal debris on a ferrogram means occuring the abrasive wear on the running surfaces of propeller shaft(Fe) and bearing(Sn/Pb).
But, the confirmation by X-ray descloses that those cutting debris observed in this case are not metal. No iron(Fe) and tin(Sn) or lead(Pb) are shown as the cutting figure. Refer to Figure 5(Fe-X-ray image. Sn- and Pb-X-ray images are ommited).
Based on this new experience, the authors have commenced a membrane filter method, as a trial, instead for a ferrography method for the plastic bearing of S/T.

9 Conclution

In conclusion, the authors believe that;

1. The condition-monitoring-based survey by used oil analysis can be applicable for propeller shaft and bearing.
2. It can be said that when the ferrography direct reading is less than 30 W.P.C./ml, the lubrication of that system is in the good and satisfied condition proving other parmeters are within the condemning limits.

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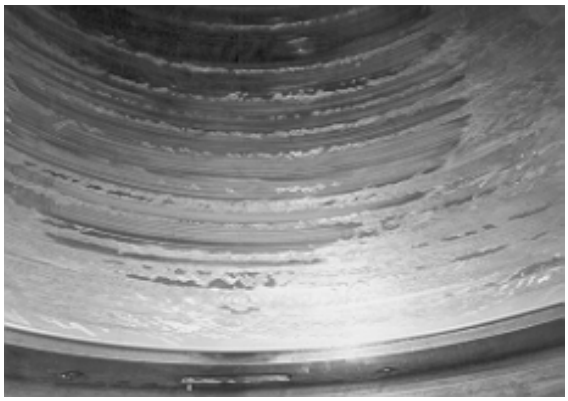
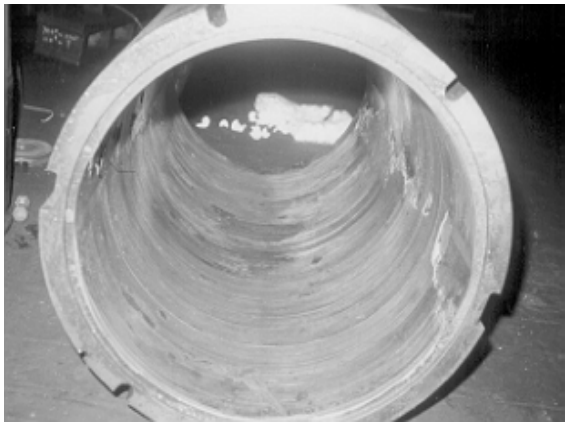
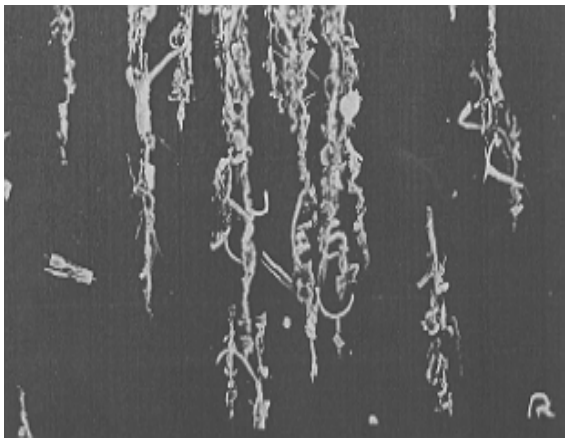


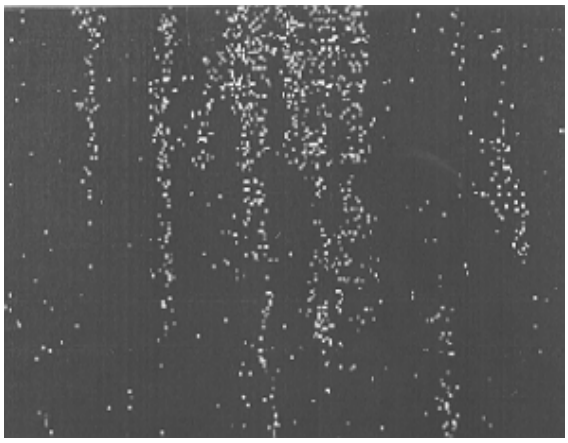
Condition C
Figure 2



Condition D
Figure 3



Secondary electron
image by X-ray
Figure 4



Fe-X-ray image
Figure 5

10 Acknowlegements

The authors acknowlege that these studies were undertaken with the cooperation of many peoples, ie shipowners, crews, dockyards engineers, and ship surveyors.

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